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Final Report

for

A Study of Anti-reflective Coatings to Enhance the UV Response of CCDs

NAGW - 3660

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The current NASA program is a Test and Evaluation (T&E) program that allows University of Wisconsin participation in a larger Internal Research and Development (IR&D) program being conducted at Ball Aerospace. While various research groups have obtained excellent results in the enhancement of the UV sensitivity of CCDs, repeatability and stability of those thin films have been major problems. The current collaboration is an engineering effort to take these technologies beyond the gross accuracy normally achieved by university groups. The Ball IR&D effort has already deposited 900-1130 Angstrom layers of Anti-Reflective thin films on inexpensive silicon substrates and on MgF_2 windows. The films are: MgF_2 and Alumina.

The present T&E Program not only attempts to provide feedback on the quality of the depositions, but also seeks to validate two testing procedures that will become critical eventually for achieving the desired properties of the thin-film structures. For example, if a thin film has optical indices approaching within a few percent of those of the bulk material, this property provides one indication that the film is high quality.

The basic test method was to measure reflectance at seven angles for each wavelength and then find the best fit of the data to the theoretical reflectance equations which can be found in several texts (e.g. O.S. Heavens 1965). The best fit algorithm starts by minimizing the variance along and near the n,k space boundary. The parameters n and k are the refractive index and extinction coefficient, respectively. When the minimum is located, the algorithm determines if it is actually on the boundary. If it is, the adjacent n,k cell of equivalent size is searched. Otherwise, the corresponding n,k values are returned as the best-fit solution. The polarization factor was also included by running the algorithm within a binary search routine.

To check the effectiveness of this technique, a sample of a cleaned, polished silicon wafer was used as a calibration vehicle. The native oxide was not removed since it was assumed to be 3 nm thick and would be an insignificant factor at 325 nm. The reflectance results are shown in Figure 1 and the inferred indices were n=4.86 and k=3.06 for the refractive index and the extinction coefficient, respectively. These agree well with corresponding published values of 5.05 and 3.21 (Palik 1985). Both of our values were within 5% of the value found in Palik (1985), a discrepancy which is smaller than the repeatability expected from successive depositions. Another extraction at 250 nm produced (1.61,3.72) compared to the published values of (1.58,3.63), an accuracy difference of 3%.

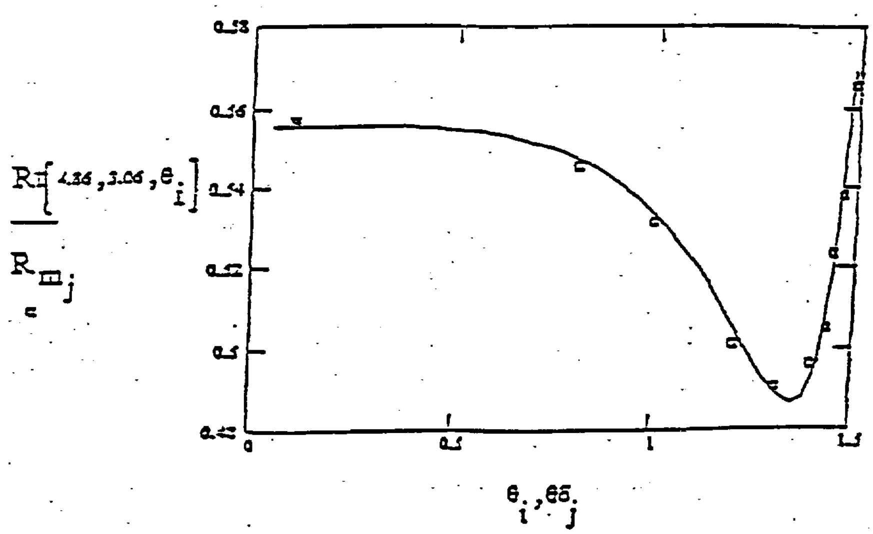

Figure 1: Reflectance data (R_m) of 325 nm light at several incident angles off of a silicon substrate. The theoretical best fit solution (Rt) implies the optical indices of n=4.86 and k=3.06 which compares well to Palik's [3] values of n=5.05 and k=3.21.

Reflectance measurements have been made on the MgF2 and Alumina films, indicating the films are of poor quality, although still adequate for evaluating the effectiveness of our testing procedures. Progress in testing has been impeded by competition from other major programs who have been tying up various machines at Ball. In addition, the UV characterization has proved to be tougher than expected. Nevertheless, we have the following optical indices to report for 90 nm of MgF2 on silicon and for 113 nm of Al2O3 on silicon. The results are summarized in Tables 1 and 2.

Table 1: Measured Optical Indices for 90 nm of MgF2 on Silicon

Wavelength (nm)	Extracted n,k	Extracted p	Deviation (%)	Palik's [1] n,k
340	1.48,0.009	...	0.98	1.39,0.000
312	1.46,0.013	...	0.44	1.40,0.000
302	1.52,0.024	...	1.06	1.40,0.000
283	1.48,0.038	...	0.67	1.40,0.000
283	1.48,0.017	0.07	0.35	1.43,0.000
260	1.47,0.025	0.07	0.61	1.44,0.000
239	1.47,0.026	0.03	0.75	1.45,0.000
220	1.41,0.039	-0.12	0.91	1.46,0.000
200	1.55,0.022	0.40	0.92	1.46,0.000
180	1.56,0.033	0.30	0.88	1.47,0.000
161	1.55,0.062	0.32	11.88	1.47,0.000
144	1.54,0.062	0.20	1.08	1.52,0.000
122	1.66,0.126	0.37	0.97	1.61,0.000*

*Values measured by Zukic et al. 1990 from thin films of MgF2 were 1.72,0.018.
[1] Palik (1991)

Table 2: Optical Indices for 113 nm of Al2O3 on Silicon

Wavelength (nm)	Extracted n,k	Extracted p	Deviation (%)	Palik's [1] n,k
283	2.08,0.000	-0.15	5.40	1.83,0.000
260	2.24,0.000	1.00	2.42	1.83,0.000
239	2.47,0.045	0.61	3.95	1.83,0.000
220	2.20,0.002	-0.33	0.74	1.83,0.000*
200	2.33,0.038	-0.03	0.96	1.85,0.000*
180	2.50,0.052	0.38	3.11	1.93,0.005
161	2.95,0.202	0.16	11.80	2.07,0.025
144	3.33,0.111	0.32	21.49	2.24,0.080
122	...	...	...	...

*Values measured by Zukic et al. 1990 from thin films of Al2O3 were 2.10,0.010 and 2.05,0.015 for 220 and 200 nm, respectively.
[1] Palik (1991)

Extracted measurements are based on reflectance data. As can be seen in Tables 1 and 2, we achieved good agreement between our results and bulk characteristics found in the literature for MgF_2, but not for Al_2O_3. As already noted, achieving optical characteristics that are similar to those of the bulk material is often used as an indication of the quality of the thin film and may not reflect uncertainties in the measurements.

Repeated measurements suggest these measurements are precise and reasonably accurate, although systematics in the results can be seen between various setups and technicians. The discontinuity in the MgF_2 results at 210 nm is attributed to a change from a bialkali to a CsTe detector, while the difference between successive measurements at 283 nm underscores the systematic uncertainties attributable to different technicians. Also, we had access to a scatterometer that was capable of providing limited information at 325 nm. For the MgF_2 film, two measurements indicated an RMS roughness of 13.2 and 14.1 Angstroms, the quality of a typical optical mirror. These data suggest the primary loss mechanism at the surface was absorption.

As noted in previous technical reports, we have fabricated under this grant the heart of a state-of-the-art vacuum chamber for measuring the Detective Quantum Efficiency (DQE) of CCDs from 120 to 300 nm. This chamber will prove invaluable in future years as we move from depositing coatings on inexpensive silicon substrates to depositing films on CCDs.

The current T&E Program is complete. It was not feasible within current funding constraints for us to attempt to assess the optical indices at CCD operating temperatures of -80 to -120 C nor to analyze the film's resistivity to appraise its effectiveness as an insulator in a bias gate structure. Nevertheless the program accomplished its primary objectives.

References:

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